NOISE EMISSIONS FROM UNMANNED AERIAL VEHICLES

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Outline

- Introduction
- Experienced Noise
    - Helicopters
- New Noise Experience
    - UAS with VTOL capability
- Concepts of operations and psycho-acoustic effects
- Research requirements for a precise noise prediction

Vehicles - Now and in Future

NOW

- Very short haul flights (≤10-15nm)
  - Small aircraft
  - Small helicopter
  - Two to nine PAX
- Operation from and to
  - small airports and
  - Heliports
- Operation for
  - Touristically driven transport, sightseeing
  - Industrial off-shore business
  - On demand VIP transportation

FUTURE

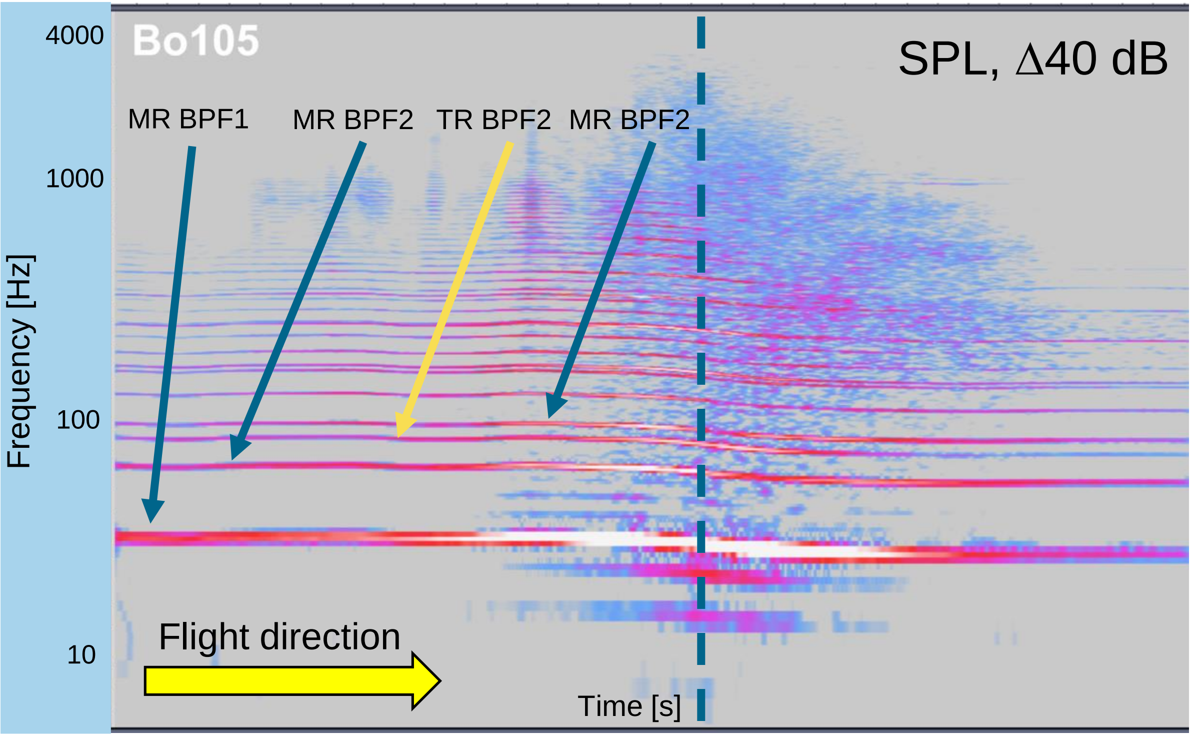
- Very short haul flights (≤10nm)
  - Small electrically powered
    - Multicopter and
    - multi jet vehicles
  - One to six PAX
- Operation from and to dedicated helipads/"vertiports"
- Operation for
  - individuals (VIP, touristic)
  - Shuttle like high frequency traffic

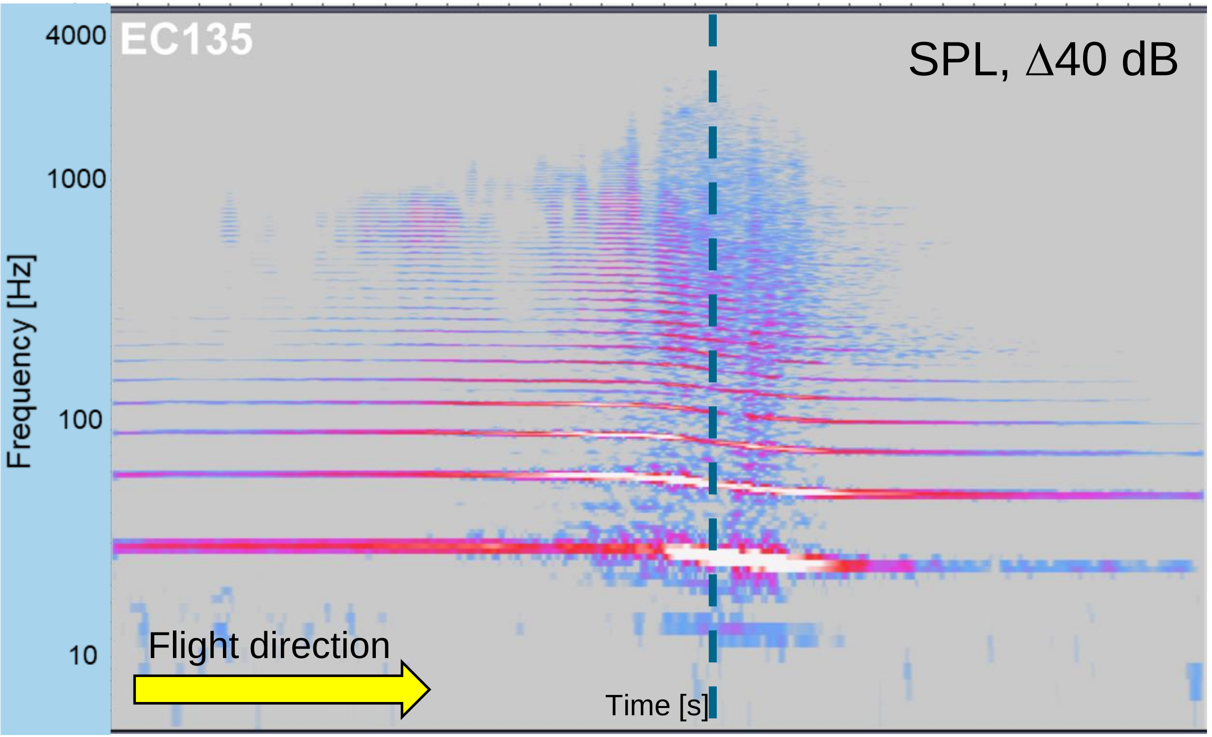
Vehicles – Acoustic Features

- Focus on vehicles with VTOL ability → no conventional fixed wing aircraft
- Leave out multi jet driven vehicles → insufficient data and experience
- Helicopter acoustics (simplified)
  - Main rotor
    - Low rpm, discrete frequencies with BPF at 10 - 30 Hz + many harmonics
    - particularly audible for 2 bladed rotors (Bell Huey, „wap wap“-sound): „BVI-blade vortex interaction in descent“
    - Similar, forward directed characteristics in fast forward flight from transonics (+ thickness noise)
    - Broadband noise due to stochastic part of blade loading
  - Tail rotor
    - Higher rpm, BPF 50 – 80 Hz for conventional tail rotors and ~ 600 Hz for the Fenestron
    - Rear arc directed high frequency noise, in particular for the Fenestron
- In general: overall noise is the energetic summation of all acoustic sources, no meaningful acoustic interference effects

Helicopter Data

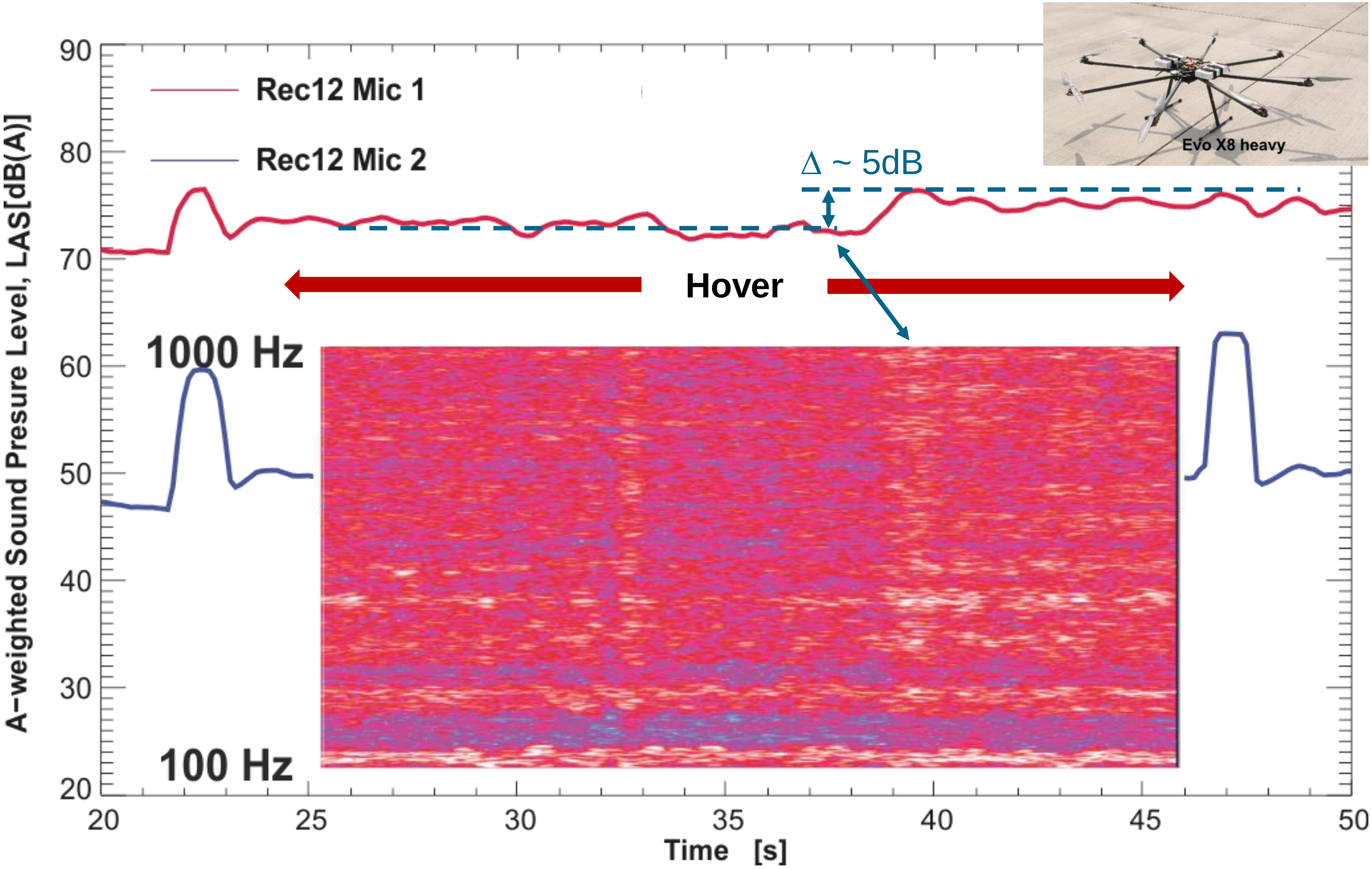
	MTOW	L_{AE}		Main rotor				Tail rotor						
	[kg]	[dB(A)]	Spped [m/s]	rpm [min^{-1}]	Blade nb.	diameter [m]	BPF	rpm [min^{-1}]	Blade nb.	diameter [m]	BPF	Spped [m/s]	MH	Cp
EC 120	1700	11: 78.1	77.2	410	3	10	20.5	4565	8	0.75	608.7	77.2	0.663	2.857
Bo 105	2600	8*: 90.0	74.7	424	4	9.84	28.3	2220	2	1.65	74.0	74.7	0.671	1.868
Bell 205	4310	8*: 87.8	56.7	324	2	14.63	10.8	1661	2	2.59	55.4	56.7	0.740	4.834
Bell 206	2018	11: 85.0	62.5	394	2	11.28	13.1	2550	2	1.65	85.0	62.5	0.700	2.920





MAESUREMENT AND MODELING OF UAS NOISE

UAS Noise Characteristics – Small Octocopter



Low frequency noise

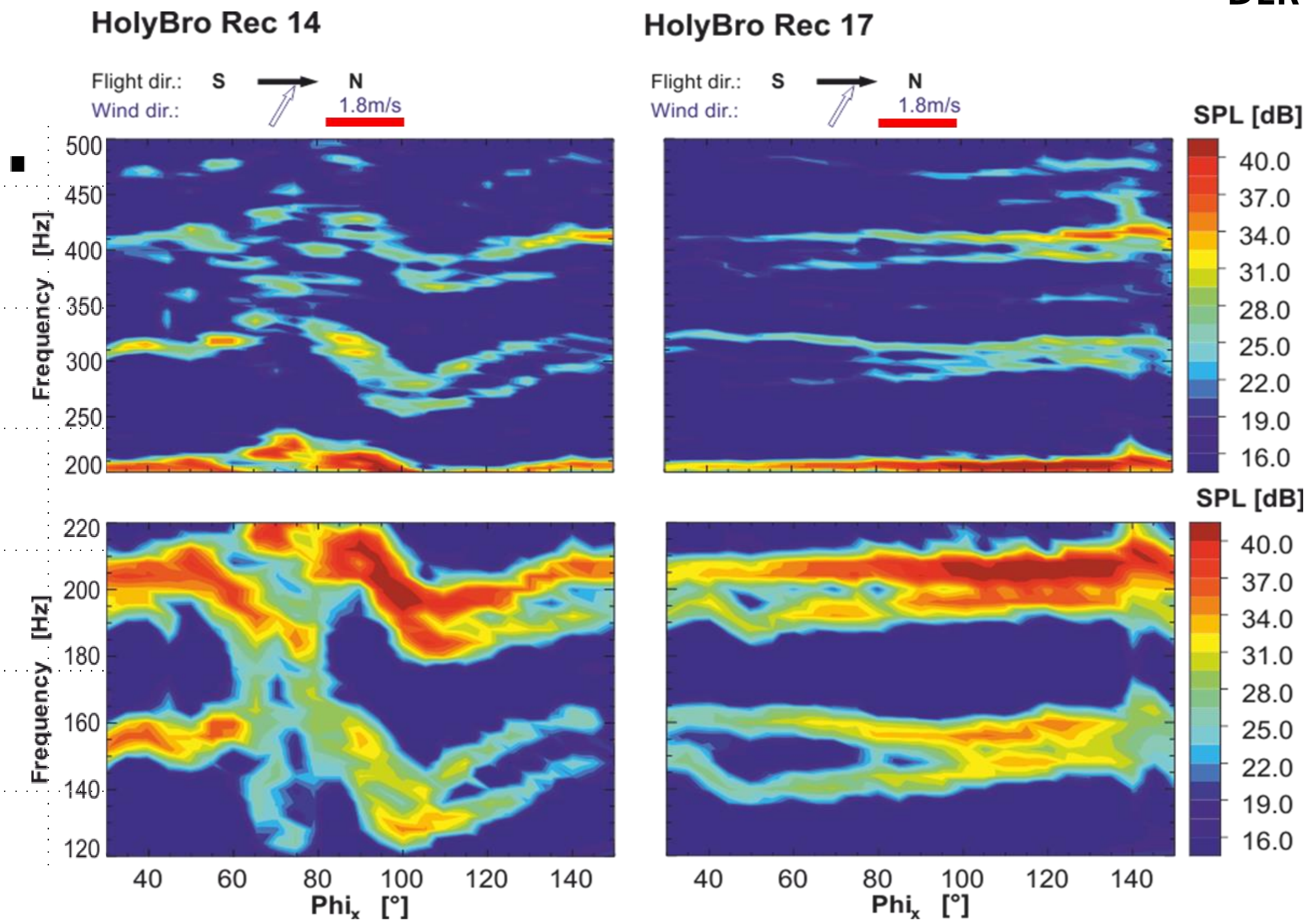
- 100 Hz to 1 kHz
- Strong tonal noise components visible
- Not stable in level and frequency

- Despite constant operating conditions (hover) a significant wind induced level increase is observed

- Wind: mean velocity, gusts and direction

Quadcopter: Tones and Directivities

- Very complex tone combinations
- Tone levels depend on wind influence
- No option for modelling due to missing rpm-data as link between UAS operation and acoustic signal
- Effect of rotor rotation pattern

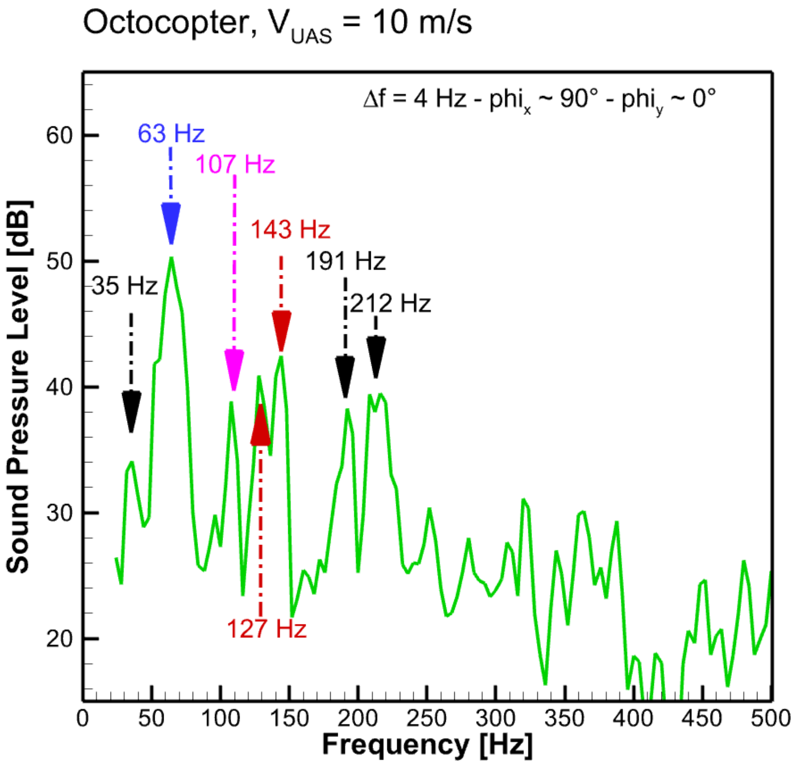


Noise Modeling

- **Target**
  - Provision of sound pressure level spectra and directivities representative for both tonal and broadband noise
  - Coupling of the noise model with a propagation tool to account for propagation effects

- **Representative**
  - Modeling depends on available databases of UAS noise
  - Separate modeling of tonal and broadband noise components
  - Account for operating parameters like
    - rpm
    - thrust
    - flight speed and
    - meteo effects

Example: Octocopter - Tonal Noise



Head wind

Rotor#	rpm [min-1]	rotation [Hz]
0	1598	27
1	1912	32
2	1931	32
3	2181	36
4	1909	32
5	2092	35
6	1820	30
7	1899	32

Tail wind

Rotor#	rpm [min-1]	rotation [Hz]
0	1666	28
1	1964	33
2	1914	32
3	2146	36
4	1852	31
5	2059	34
6	1860	31
7	1992	33

	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7
Narrow peak frequency [Hz]	35	63	107	127	143	191	212
[1/min]		BPF		2BPF		3BPF	
			2BPF of 27 Hz		2BPF of 36 Hz		4BPF of 27 Hz

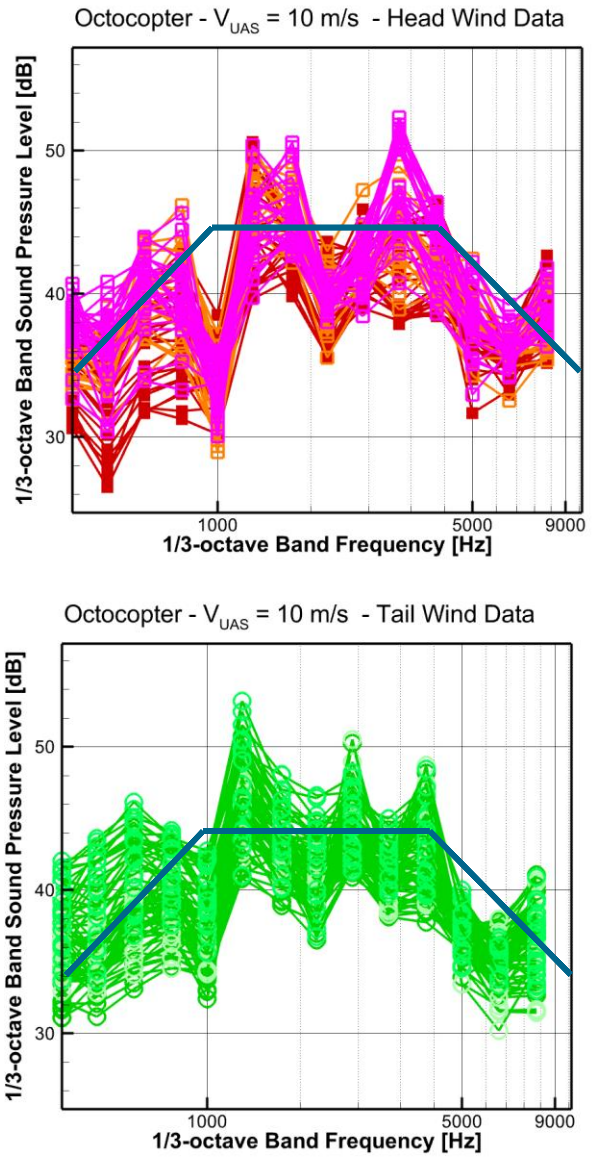
- **BPF pattern will be used for prediction:**
  SPL(2BPF) =SPL(BPF) -8dB and SPL(3BPF)= SPL(BPF) -10dB

$$M_H = \frac{1}{c}\sqrt{\left(\frac{\pi D N_P}{60}\right)^2 + v^2}$$

- Tonal noise is predicted on basis Dobrzynski‘s work: "Ermittlung von Emissionskennwerten für Schallimmissionsrechnungen an Landeplätzen", DLR report IB 129-94/17
- Parameter: helical blade tip Mach number and blade loading
- Rotor/engine: blade number, blade diameter and number of rotors, power, rpm

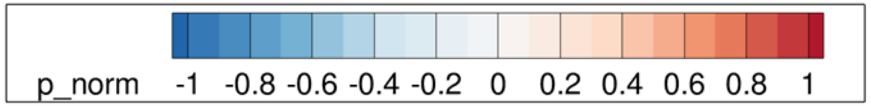
$$c_{P,B} = \frac{c_P}{n_B} = \frac{1000 * P}{\rho\left(\frac{N_P}{60}\right)^3 D^5 n_B}$$

Example: Octocopter - Broadband Noise

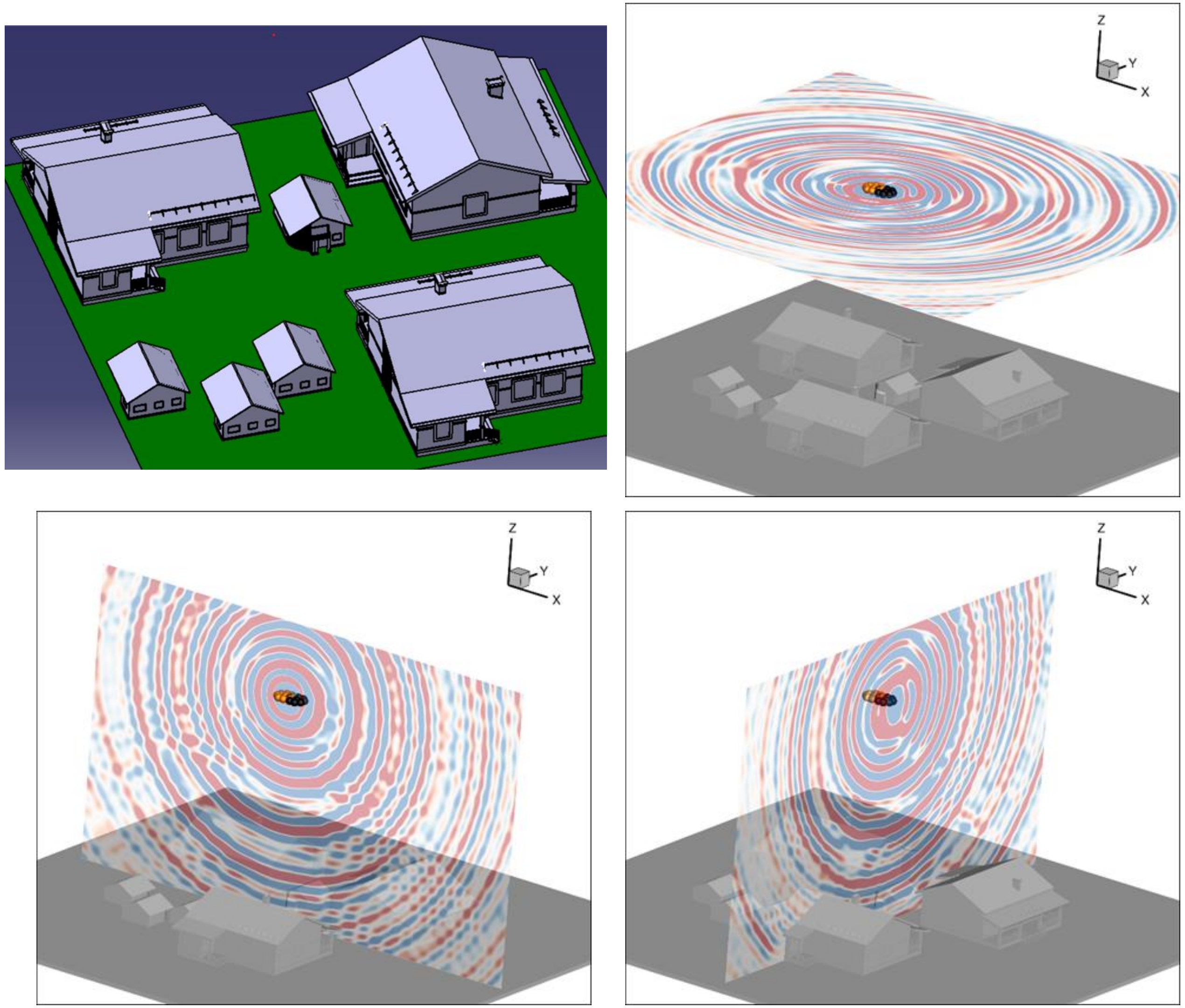


- Broadband noise model
  - 400 Hz to 1250 Hz
    linear increase from 35 dB to 45 dB
    SPL(f) = 0.018*f_m + 30.28 dB
  - 1250 Hz to 4000 Hz
    constant 45 dB
  - 4000 Hz to 10 kHz
    linear decrease from 45 to 35 dB
    SPL(f) = -0.00167*f_m + 38.32 dB
  - Model provides correct OASPL
  - No consideration of wind influence
  - Omni-directional directivity

UAS Noise Simulation

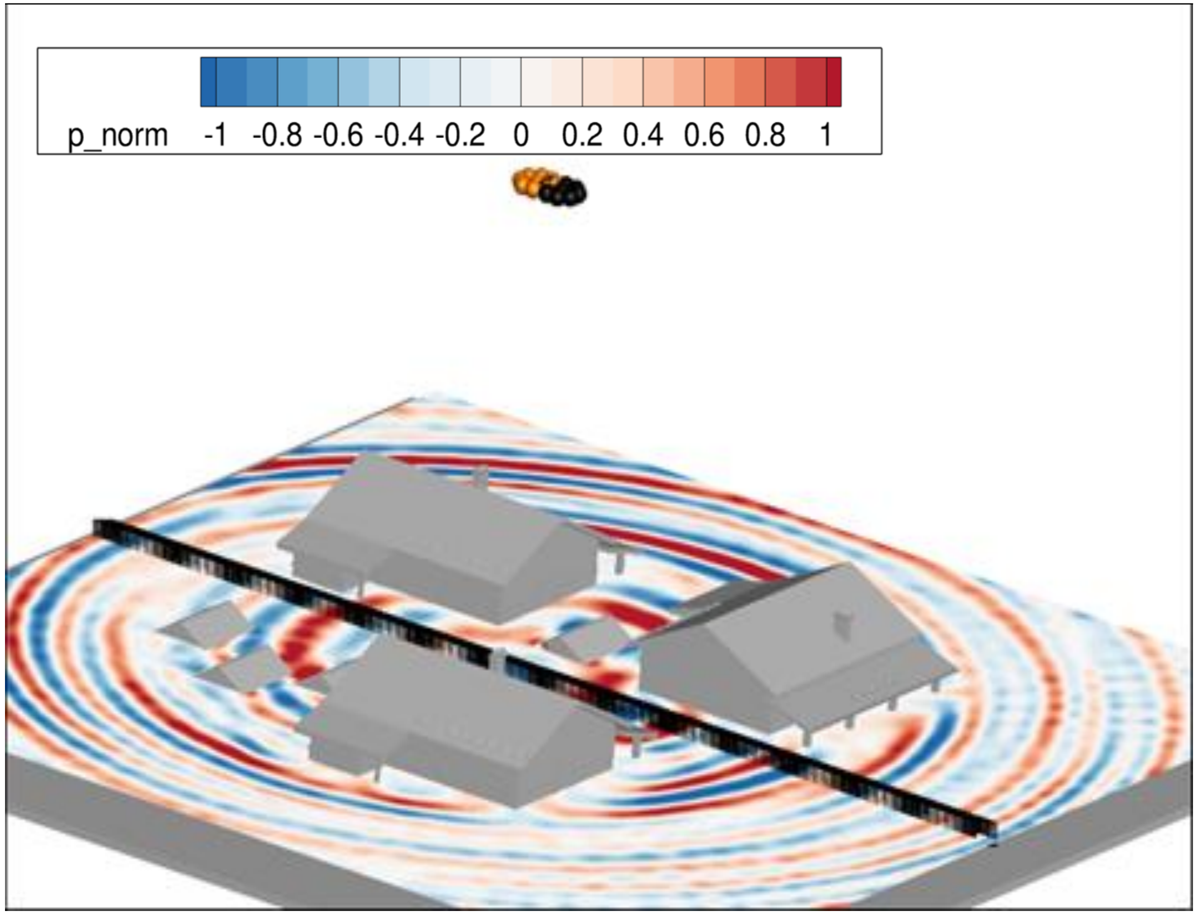


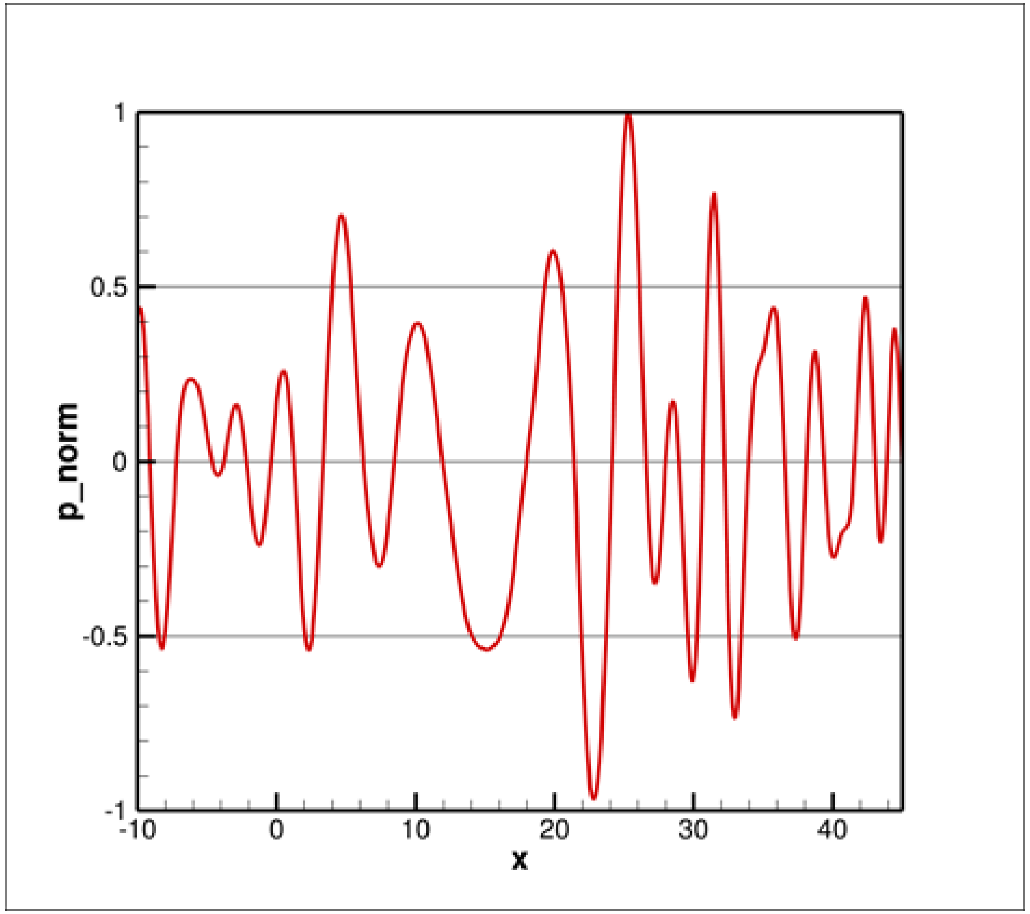
- The empirical noise model was used as input for a numerical simulation of the acoustic field generated by a moving UAS
- DLR CAA code: PIANO-IBM
- Strong interference patterns
- Explicitly annyoing in quiet environment
  → modeling a rural scenery



UAS Noise Simulation

- Resolve the sound pressure pattern along the „main road"
- Within very short distances the sound pressure levels double or halve





Michael Pott-Pollenske, Institute of Aerodynamic and Flow Technology, May 30th 2024

Methodology to Improve the Noise Prediction
Basic Concept to Establish a Realiable Tool Chain

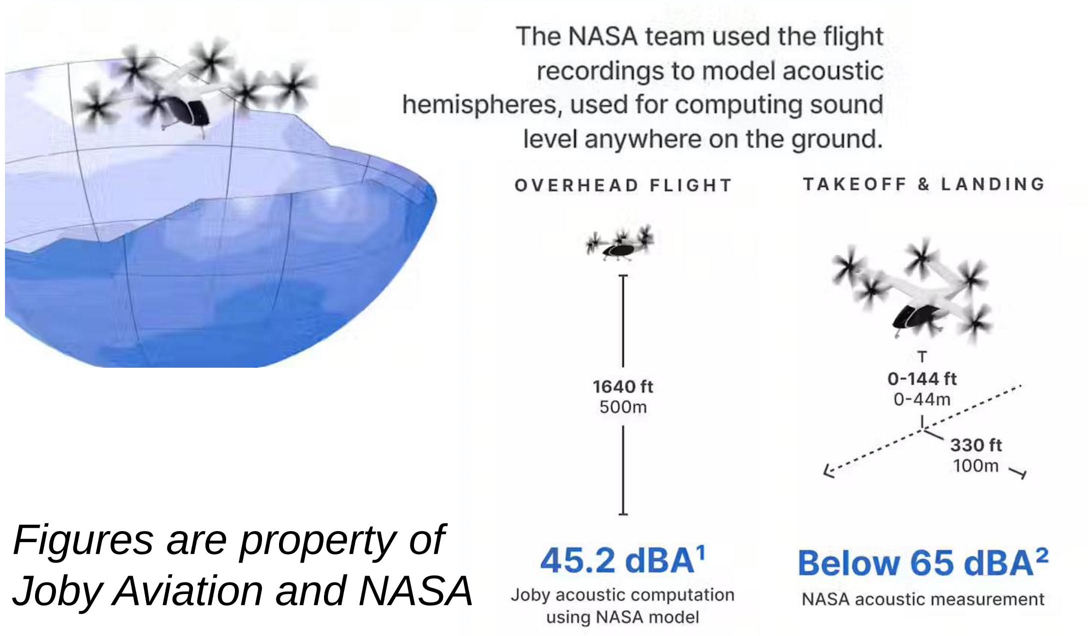
<table>
<tr><th>Task</th><th>To do</th></tr>
<tr><td>Test the source itself</td><td>One propeller
parametric study with and without wind influence (mean velocity and gusts)
Wind tunnel studies on models
Numerical simulations of the wind tunnel situation</td></tr>
<tr><td>Test multiple sources</td><td>Number of propellers >1
Test different propeller configurations
Number of propellers
Sense of rotation, rotation patterns
Rotate propeller assembly (Tilt wing / tilt rotor like)
Wind tunnel studies on simple models
Numerical simulations of the wind tunnel situation</td></tr>
<tr><td>Test the vehicle</td><td>Select a representative vehicle layout (Multicopter, Tiltwing or Tiltrotor) for model tests in the wind tunnel
Numerical simulations of the wind tunnel situation
Numerical simulations of the full scale vehicle
Flight test with full scale vehilce for validation</td></tr>
</table>

Conclusions

- The operation of Multicopter type UAS is a challenge in terms of noise
  - The vehicles will operate in close vicinity to living areas and in low altitudes
  - The flight control (yaw, pitch, roll, climb/descent and speed control) is rpm driven with direct impact on propeller / rotor noise
  - For the acoustic classification a single physics based acoustic metric will not be sufficient, psychoacoustic parameter should be considered

- Most manufacturers keep their operational data incl. noise secret. It is not possible to rely on full scale data generated by the real vehicle, except for Joby cooperating with NASA

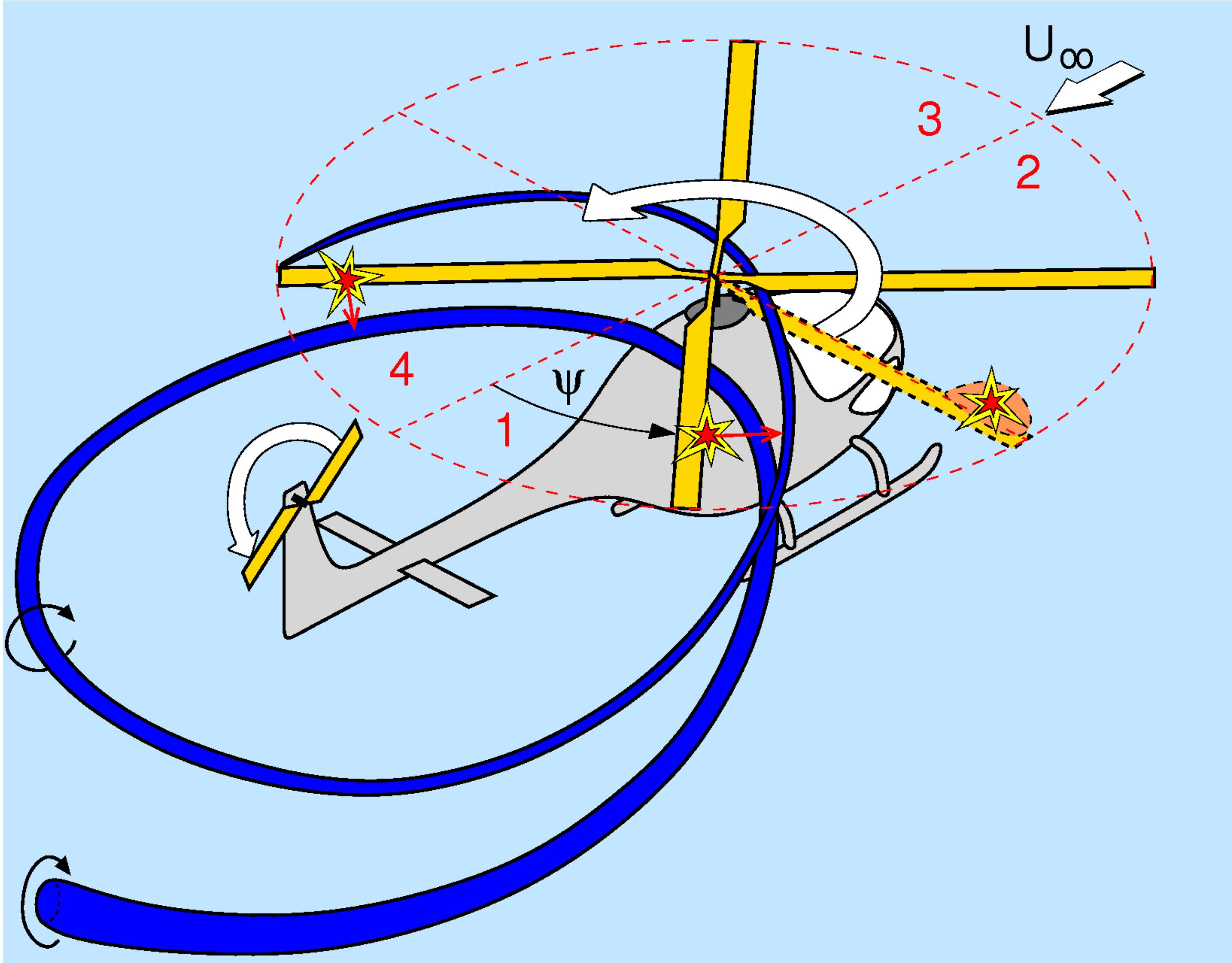
NASA Tests the Joby Aircraft



Figures are property of Joby Aviation and NASA

- Establish a valuable database
- Validate research codes
- Gain technical advantage

- ➔ benefit for U.S. authorities and citizens
- The presented work shows identical capabilities of the European research institutes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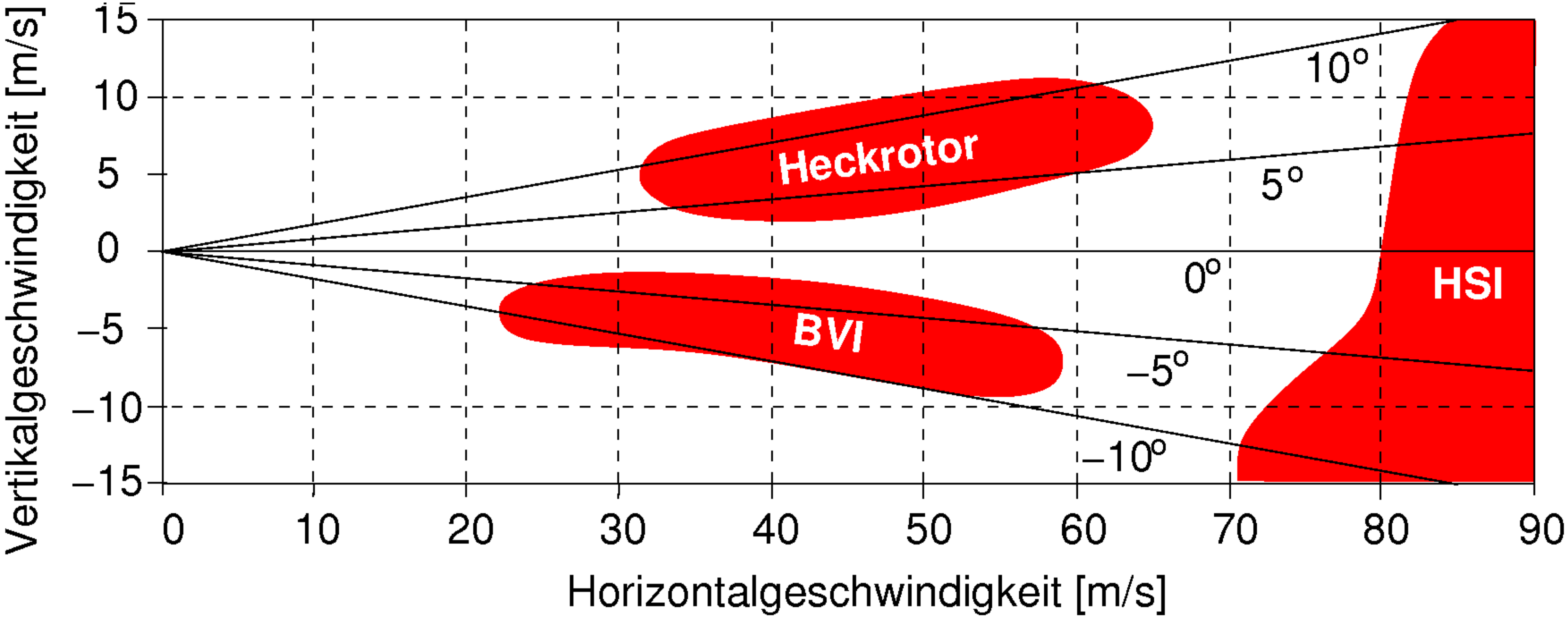

Vertikalgeschwindigkeit [m/s]
15
10
5
0
–5
–10
–15
Heckrotor
BVI
HSI
10°
5°
0°
–5°
–10°
0
10
20
30
40
50
60
70
80
90
Horizontalgeschwindigkeit [m/s]

Imprint

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